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# Effective Heat Transfer Enhancement in Finned Tube Heat Exchanger with Different Fin Profiles

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***Abstract-During cross flow in a heat exchanger, heat transfer in the front portion of the tube is more compared to back portion of the tube. This is due to less formation of vortices at the backside of the tube. For uniform heat transfer to take place throughout the tube, it is necessary to increase the vortex formation at the rear side of the tube. The aim of this study is to explore the possibilities of improving the flow structure and thereby increasing uniform heat transfer around the tubes by introducing special type of fin arrangement over the tubes. The effect of shape and orientation of the fin on vortex generation and respective heat transfers are studied numerically. It have been identified that by introducing special type of fin arrangement over the tube there is a possibility for increase the vortex formation at the rear portion of the tube, which significantly leads to creation of uniform heat transfer all around the tube.***

***Keywords-*** **Heat exchanger, flow structure, vortex, heat transfer enhancement**

INTRODUCTION

Fin and tube Heat exchangers are used in various applications ranging from cooling system in electronic component to heat transfer process in evaporator. The need of heat exchanger device is valuable in many fields. More focus is needed on the heat exchanging capability of such type of heat exchangers. Thermodynamically, the capability of heat transfer mainly depends upon three parameter (1) The Air-side Convective Thermal Resistance; (2) The Wall Conductive Thermal Resistance; and (3) The Liquid-side Convective Thermal Resistance. Here the last two parameters can be predictable but the Air-side convective Thermal Resistance is greatly affecting the process. The reason for this is a thermopysical property is playing an important role in that region. Thermo physical behavior is the fluid dynamic nature of the air around the object due to which the major outcome will be in thermal nature. In practical case the dynamic nature of the air around the tube will create possible wake region in the rear portion of the tube because of less formation of vortex in that part. The front portion of the object will be subjected to more heat transfer which causes ununiform heat transfer in the tube. This problem can be avoided by introducing the new concept of vortex generator. Vortex generator like wings and winglet are used to increase vortex in the flow fields .The methods for creation of vortex are, (1) developing boundary layer; (2) Flow destabilization; and (3) Swirl. Vortex generator will create flow destabilization in wake region and make the swirl. Hiravennavar[1] numerically studied the flow structure and heat transfer enhancement by winglet pair. He predicted that heat transfer on tube with winglet is more than without winglet. K. Torii[2] studied common flow down and common flow up method experimentally, he found that common flow up method will enhance heat transfer with less pressure drop and create a nozzle like passage in rear side of the tube and reduces wake formation by separation delay. Jin-
Sheng Leu[3] numerically and experimentally examined heat transfer and flow in plate and fin heat exchanger and identified vortex generator promote heat enhancement in wake region and also found that a reduction in fin area can be achieved by using vortex generator fin in place of plate fin.

A. Joardar[4] investigated experimentally air side heat transfer enhancement by vortex generator, the heat transfer rate increase from 16.5% to 44% from baseline configuration in common-flow-up orientation. Jiang Chun Bo[5] carried out numerical and experimental investigation on turbulence characteristics in wake region of circular cylinder. He used finite element method to stimulate the turbulence in wake region. It had been proved that the vortex shedding causes a change in flow pattern and also the concentration of field is related to the vortex shedding. Mihir Sen[6] studied experimentally and numerically the effect of fin spacing over tube in single row fin and tube heat exchanger. It is evident that the heat transfer will increase if the spacing of the fin is about to a mean distance and there is chance of increase in heat transfer if there is a fluid recirculation on the downstream of the tube. M.F. Tachie[7] examined experimentally using practical image velocimetry in staggered tube in cross flow with inlet velocity based Reynolds number in which the flow is of anisotropic in nature it is due to shear level is high. Besir Sahin[8] investigated experimentally the flow structure of the flow around circular cylinder in a rectangular duct. He visualized the creation of Horse shoe vortex formation from the upstream in wake region by boundary layer separation. The primary vortex is formed by combining the developing vortex from horse shoe and it enhances the heat transfer rate. M. Salinas-Vázquez[9] numerically approached flow around circular tube bundle using Large Eddy Simulation and immersed boundaries approach. He found that flow condition in tube are affected by interaction of wake and boundary layer separation, which causes change in heat transfer rate by convection

## I. PHYSICAL MODEL

In this work, tube without fin and finned tube heat exchanger are studied separately. In this case the fins are arranged longitudinal direction of the tube. There are two types of vortex generators namely wings and winglet. In this study winglet type fin with much different design and alignment with the flow direction is considered. The fin material is taken as Aluminum of thickness 2.18mm for better thermal conductivity. Usually winglets are placed over the plate finned

tube heat exchanger but in these case fins are placed over the tube without the need of plate.Fig.1a and fig.1b shows the dimensions of the fin and the position over the tube. The fins are placed in common flow up direction. The distance between the fins in upstream is 3.63mm inclined at an angle of α=15˚.Fig.2 shows the computational domain, the first tube of diameter D =10.67 mm, is located at 31.76 mm from the inlet of the flow channel. The actual computation domain is extended by 5H at the inlet to maintain the inlet velocity uniformity and the domain is extended by 30H at the exit to ensure a recirculation-free flow there.

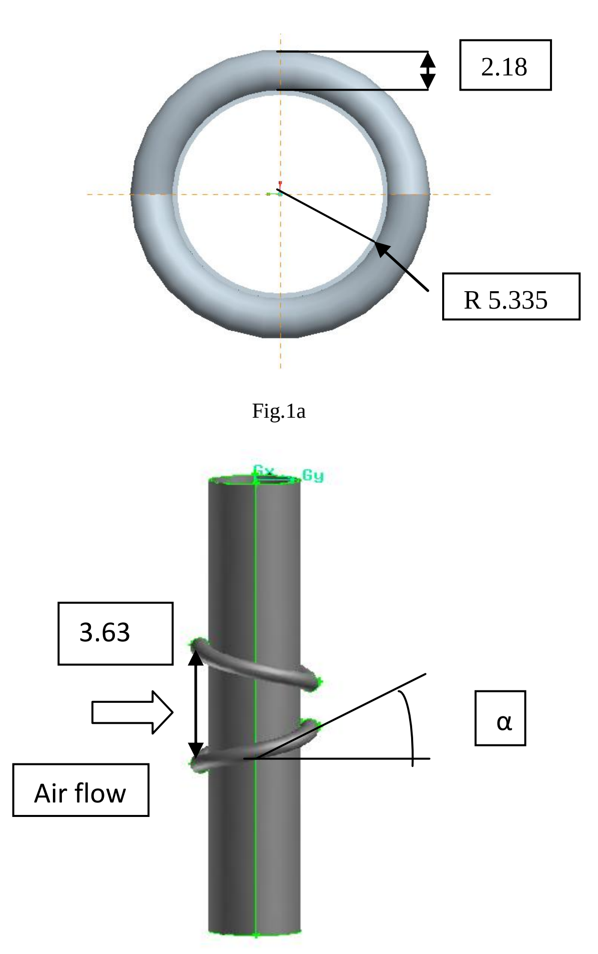



Fig.1a

Fig .1b Vortex generator and placement around the tube (all dimensions are in mm)

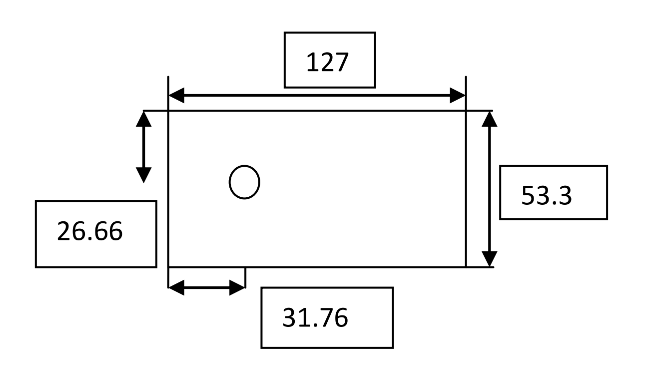



Fig .2 Computational Domain (all dimensions are in mm)

## II. BOUNDARY CONDITIONS AND GOVERNING EQUATIONS

The fluid is considered incompressible with constant properties. According to Ferrouill, the generation of longitudinal vortices is a quasi-steady phenomenon. Consequently, due to the low inlet velocity, the flow in the channel of the compact heat exchanger is assumed to be laminar and steady. Fin thickness and heat conduction in the fins and vortex generators are taken into account. The governing equations in Cartesian coordinates can be expressed as follows:

Continuity equation: $\partial/\partial xi\ (\rho ui) = 0$ (1)

Momentum equation: $\partial/\partial xi\ (\rho uiuk) = \partial/\partial xi\ (\mu\ (\partial uk/uk)) - \partial p/\partial xk$ (2)

Energy equation: $\partial/\partial xi\ (\rho uiT) = \partial/\partial xi\ (\Gamma\ (\partial T/\partial xi))$ (3)

Where $\Gamma = \lambda/cp$ (4)

## III. NUMERICAL MODEL

The model of the finned tube is designed in PROE and is then imported in GAMBIT. Since there are three regions of heat transfer to take place the whole domain is divided into three parts 1.air side convection region 2. Solid conduction region 3. Water side convection region. Each domain is separately splitted in GAMBIT .In GAMBIT meshing whole domain with different fin region is difficult if there is rough mesh. The flow structure cannot be clearly identified in that mesh. So, the edges of the domain are meshed using interval count and then the individual faces are meshed using triangular mesh of interval size. Finally the whole volume is meshed using tetrahedral meshing. The Navier-Stokes and energy equations (1) to (4) with the boundary condition are solved by using a computational fluid dynamics code (Fluent). The convective terms in governing equations for momentum and energy are discretized with the second-order upwind scheme. The coupling between velocity and pressure is performed with SIMPLE algorithm.

## IV. PARAMETER DEFINITION

The definition of Reynolds number, Nusselt number and Heat transfer coefficient are as follows:

Properties of Air at 37.6˚C:

Pr=0.699

$\nu = 16.96*10^{-6}\ m^2/s$

$k = 26.56*10^{-3}$ W/mK

$Re_a = (u\ D)/\ \nu$

Flow over cylinder:

$Nu = C\ Re^m\ Pr^{0.33}$

$h_a = (Nu\ k)/D$

Properties of water at 18.77˚C:

Pr = 7.02

ν = 1.006*10¯6 $m^2$/s

k = 597.8*10¯3 W/mK

$Re_w = (u\ D)/\ \nu$

Flow through cylinder:

$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$

$h_w = (Nu\ k)/D$

## V. RESULTS AND DISCUSSION

*Simulation parameters*

Fluid properties

Inlet temperature of air: 310.6 K.

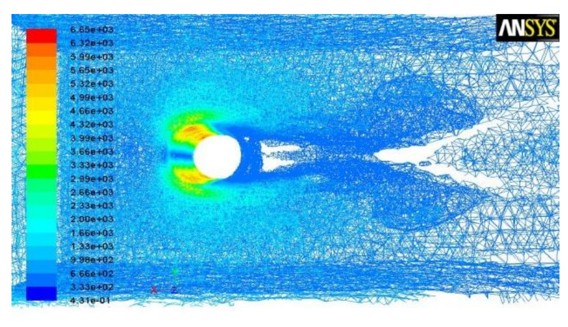
Reynolds number: ranges from 550 to 880.

Inlet temperature of water: 291.77 K.

The inlet air velocity: 1.06 m/s

The inlet water velocity: 0.45 m/s

{Source: Ya-Ling He et.al[10]}



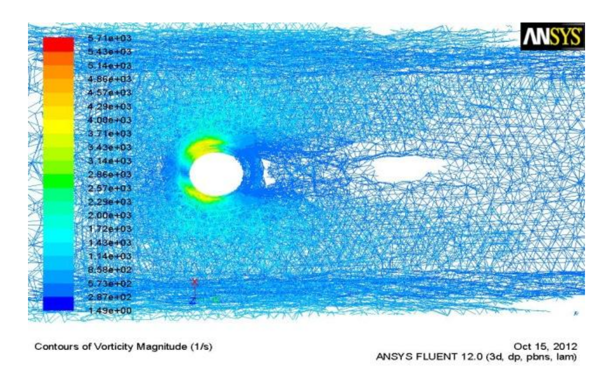




Fig.3 and fig.4 Vortex formation in baseline tube and finned tube respectively

The above initial conditions are provided for simulation, based on previous literature. The vortex formation for normal tube is shown in fig.3 in which we can see there is wake region formed behind tube region, due to fewer vortices formation in that region. The cause for the formation of fewer vortex is that the chance for boundary layer separation from the main flow due to shear layer formation is less and the time taken for conversion of developing vortices into primary vortex is delayed.

In fig.4 it can be visualized that the wake formed in modified finned tube is reduced and there is maximum vortex formation behind the tube. This is because of providing fin in different orientation. In this case the fin positioning provides a narrow nozzle like projection which in turn creates a maximum shear layer in boundary layer and it induces combining of developing vortex in advance. These advance vortex reduce the wake region from which we can get a complete flow structure of fluid all around the tube. The clear visualization of flow pattern change is seen in vector plot fig.5. It is clearly visible that the direction of the fluid flow changes from its normal flowing direction to reverse direction which causes the reduction in the wake region of the flow. The factors which mainly enhance the heat transfer are the thermo physical nature of the air side convective thermal resistance. If there is a chance of reducing this resistance then there will be an increase in heat transfer rate. Accordingly to the new fin orientation there is maximum flow around the tubes on both upstream and downstream. The ununiform flow of air around the tube is normalized into uniform flow structure.

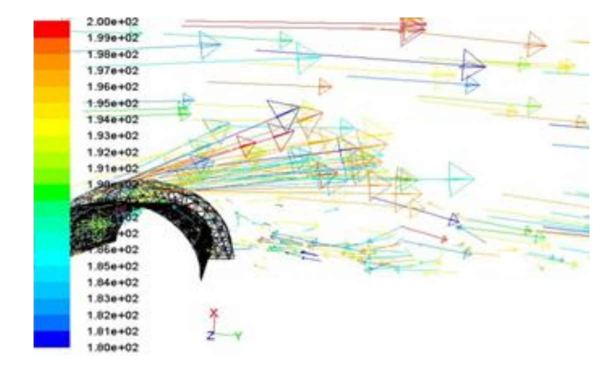
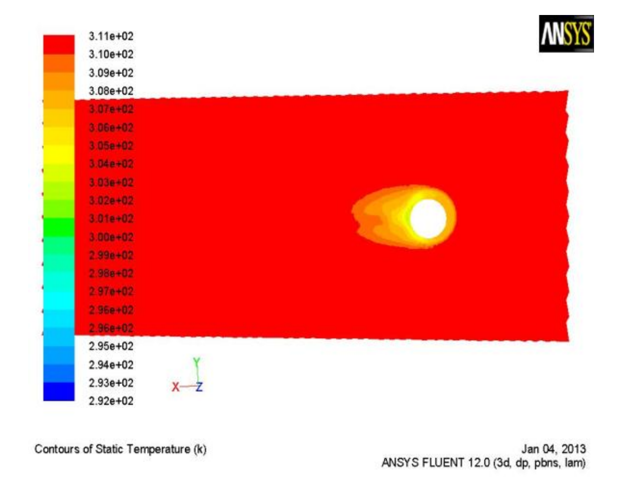



Fig.5 Vector plot of vortex in finned tube



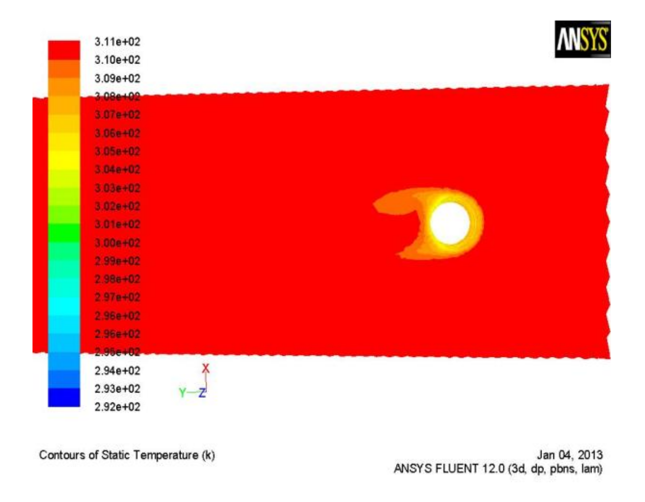
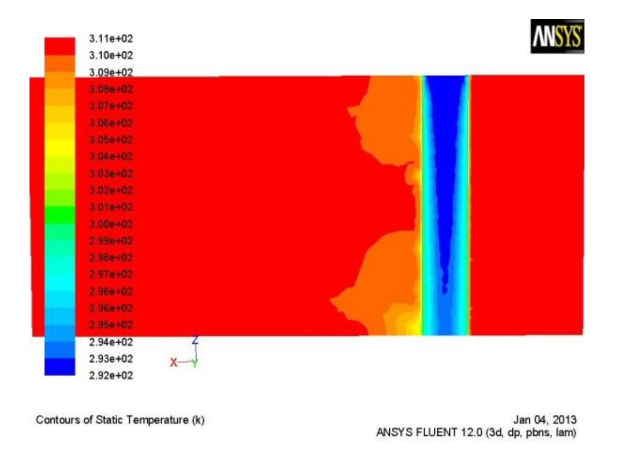



Fig.6and fig.7 Heat transfer in baseline tube and finned tube respectively

Usually the process of heat transfer will be more in the upstream of the tube than the downstream, due to flow structure. This leads to ununiform heat transfer between upstream and downstream side with less heat exchanging ability .Fig .6 shows heat transfer in baseline tube. It is evident that the downstream of the tube is subjected to less heat transfer because of wake formation. In fig .7 heat transfer is improved because of reduction in wake region.fig .8 and fig .9 is the cross sectional view of the heat transfer from air to water side.Fig.8 depicts the middle portion of the downstream side where there is less heat transfer. In fig .9 a continuous heat transfer can be visualized. The temperature distribution along the radial direction is shown in fig .10 for baseline tube. In that plot there is lot of void spaces in temperature distribution plot in major part of radius. This is due to ununiform heat transfer between upstream and downstream sides. This void space is seen reduced in fig .11 which is the temperature distribution in modified finned tube



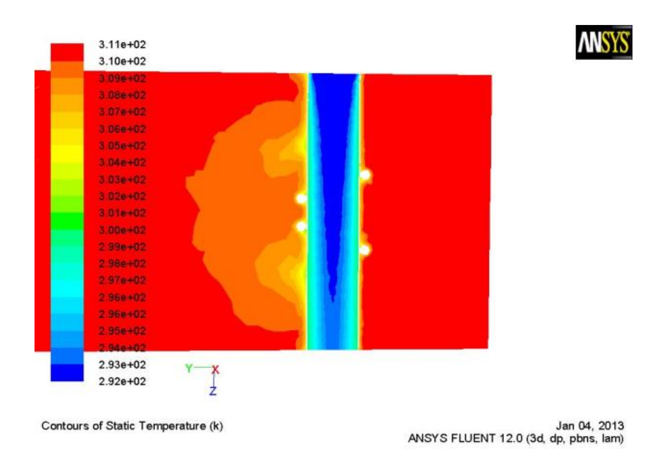




Fig.8 and fig.9 Heat transfer in baseline tube and finned tube respectively in cross sectional

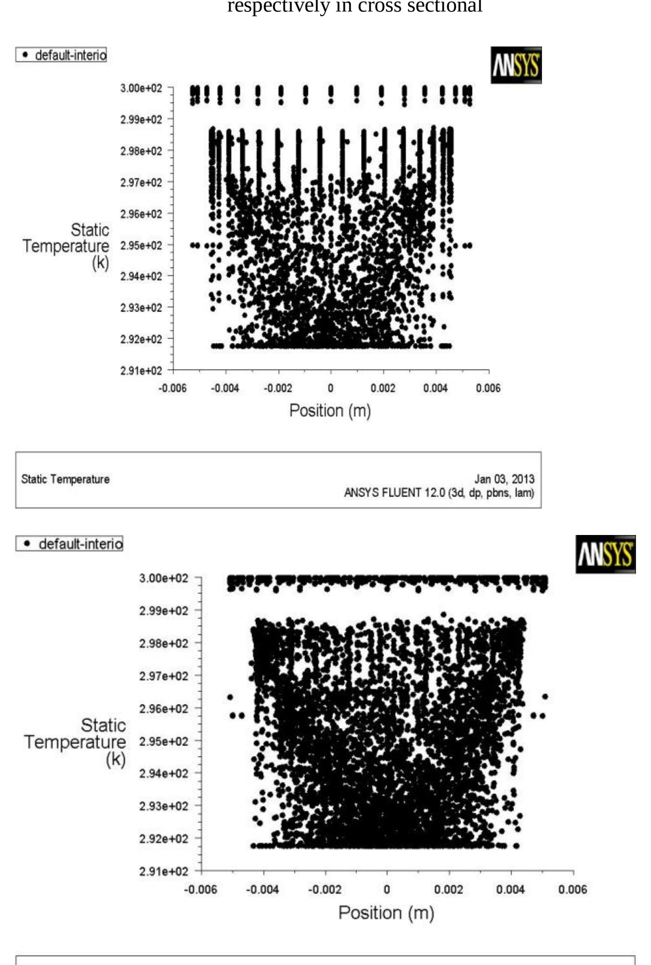



Fig.10 and fig.11 Temperature distribution in baseline tube and finned tube respectively

## VI. CONCLUSION

In this paper, three-dimensional numerical simulations are employed to investigate the flow structure in baseline tube and modified finned tube. The winglet pair generated vortices that can delay the boundary layer separation, and reduce the size of tube wake. In the "common-flow-up" orientation of the winglet pair, a constricted nozzle-like passage is created between the winglet pair and the aft region of the tube and hence the fluid is accelerated in this region. The accelerated flows not only delay the boundary layer separation but reduce the tube wake by making a primary vortex in advance than baseline tube. Since there is a creation of complete flow all around the tube the chance of heat enhancement is more and it is evident from the simulation result. The flow structure over the tube had major influence on the heat transfer process. If the angle of attack is changed definitely there is a chance of getting a complete uniform temperature distribution over the tube, which will increase the heat exchanging capacity of the heat exchanger and performance of the device will be increased automatically

### Nomenclature

D outer tube diameter (m)

h heat transfer coefficient (W/$m^2$ K)

Nu Nusselt number

Re Reynolds number

T temperature (K)

Pr Prandtl number

u velocity (m/s)

### Greek symbols

$\alpha$ angle of attack (˚)

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